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Art. IV.—*Notes on the Physiography of the Geelong District.*

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Introduction.

This paper discusses the following matters:—

(i) the altitude of the Otway Ranges in the Tertiary sea;

(ii) the post-Tertiary earth-movements and vulcanicity;

(iii) the development of the drainage system.

Altitude of the Otway Ranges in the Tertiary Sea.

The Jurassic rocks of the central portion of the Otway Ranges attain an altitude of 2,200 feet, and are flanked by marine Tertiary sediments of which the highest is about 900 feet. The Tertiary beds are limestone in the lower parts, and coarse sand in the upper.

This flanking relationship of the Tertiaries to the Jurassic was interpreted by Wilkinson (1865), Krausé (1874), Stirling (1901) and Hall (1911) to indicate that the Otways were an island of nearly 1,500 feet altitude in the Tertiary sea. Recently Hills (1935) has suggested that the Otways were completely submerged, and received a capping of Tertiary sediments, which was removed by denudation after the supposed post-Tertiary uplift. His objections to the earlier interpretation are:—

(*a*) absence of evidence of littoral facies in the Tertiaries;

(*b*) absence of evidence of existence of former shore lines;

(*c*) the deep dissection of the central portion of the Jurassics, which appears to be so vigorous as to indicate post-Tertiary uplift.

Regarding (*a*) it is true that littoral facies are rare in the Otway Tertiaries, though common enough in the parallel case of the Barrabool Hills, where the Tertiaries flanking the Jurassic have been shown (Coulson 1937) to contain pebbles of Older Basalt and (rarely) of Jurassic sandstone. The only instance of a boulder bed known in the Otway Tertiaries is at the base of the limestone of Alkemade's quarry, Kawarren, where a thin bed of Older Basalt pebbles can be seen. Three reasons may be advanced for the absence of littoral facies:

(i) the softness of the Jurassic gives a very short life to its detrital pebbles;

(ii) although the chances of Jurassic pebbles being included in the Tertiary limestone were fair, owing to the quiet water, they were remote in the case of the shallow-water Tertiary sands;

(iii) exposures of the contact between limestone and Jurassic are extremely rare, in fact, the author has not yet located one, whereas the contact of Tertiary sand and Jurassic can be seen at many places.

Regarding (*b*), the lack of evidence of the existence of former shore lines (this must also be admitted) and is more difficult to explain. The present shore line has characteristic rock-platforms, a few sandy pocket beaches at river mouths, occasional shingle beaches, and rare sea-caves. It is reasonable to suppose that similar features were developed at sea level in Tertiary times. Two possible explanations present themselves: (i) the sea-level in the Tertiary may have been steadily rising, as shown by the lithological change from limestone to sandy beds, and there may not have been a still-stand of sufficient duration to develop the features enumerated.

(ii) The features may have developed, and have since become obliterated by denudation. This is very likely on account of the softness of the Jurassic, and the rapidity of atmospheric and aqueous erosion in the area. Rock-platforms would become flat spurs, of which there are plenty in the ranges; the sand and shingle deposits of the beaches would be removed or obscured by vegetation, and the sea caves would in time collapse. Before the construction of the Great Ocean Road, several aboriginal shelter caves were known, but at the present time Ramsden's Cave (Hardy 1910) is the only one of any size above high water level.

Regarding (*c*) the deep dissection of the central portion of the ranges, the youthful appearance of the streams is due to rejuvenation by the post-Tertiary uplift, but, as will be shown later, they were initiated in Tertiary times when the Otways were an island.

A serious difficulty with the view of Hills is in the removal of the supposed universal capping of Tertiary sediments over the Jurassic. Such sediments would presumably be arenaceous like the present uppermost beds, and their thickness would be of the order of 1,500 feet. That every vestige of this great thickness of sandy beds should have been removed from the upper portions of the ranges is beyond belief; there would assuredly be large residuals of it, and the stream valleys would be choked with the practically indestructible detritus from the sand. But as is well known, the stream valleys in the higher Otways are singularly deep, steep-sided, and narrow, without alluvial flats. It is not until after the 800–900 foot level is reached and the original Tertiary beds encountered, that the valleys widen out and become sandy. Clearly there never was a capping of Tertiary sediment over the Jurassic. Probably the marine sediments never exceeded the 900 foot level.

The theory of total submergence is therefore untenable, and the earlier view is retained here, that the Otway Ranges constituted an island in the Tertiary sea.

Post-Tertiary Earth Movements and Vulcanicity.

At the close of the Pliocene period and throughout the Pleistocene, the Geelong district suffered from a number of widespread shallow faults, and a few fold movements, and contemporaneous volcanic eruptivity on a grand scale. These processes have been dominant in determining the present topography.

It is probable that the general uplift of the whole area preceded the faults about to be described, and that it took place immediately at the close of the Upper Pliocene sedimentation. However, no great time interval elapsed before the faulting began, and probably differential stressing due to the uplift initiated it. The sketch map (Fig. 1) shows the main faults of the area.

FAULTS.

1. Rowsley-Anakie-Gheringhap fault.
2. Anakie-Lovely Banks fault.
3. Barrabool Hills-Curlewis fault.
4. Moolap-Leopold trough fault.
5. Corio Bay-Port Phillip Bay-Bass Strait faults.
6. Otway Ranges faults.

FOLDS.

1. Waurn Ponds Monocline.
2. Curlewis contorted beds.
3. Torquay and Anglesea anticlines.
4. Folding in the Otway Ranges.

1. *Rowsley-Anakie-Gheringhap fault.*

This pivotal fault commences in the Lerderderg district and extends 30 miles south through Rowsley and Anakie to Gheringhap. The maximum throw of 800 feet is at the northern end; it is about 500 feet at Anakie but disappears entirely near

Gheringhap. The fault has displaced Newer Basalt (Fenner 1918) of Pleistocene age, and is therefore late Pleistocene or even younger.

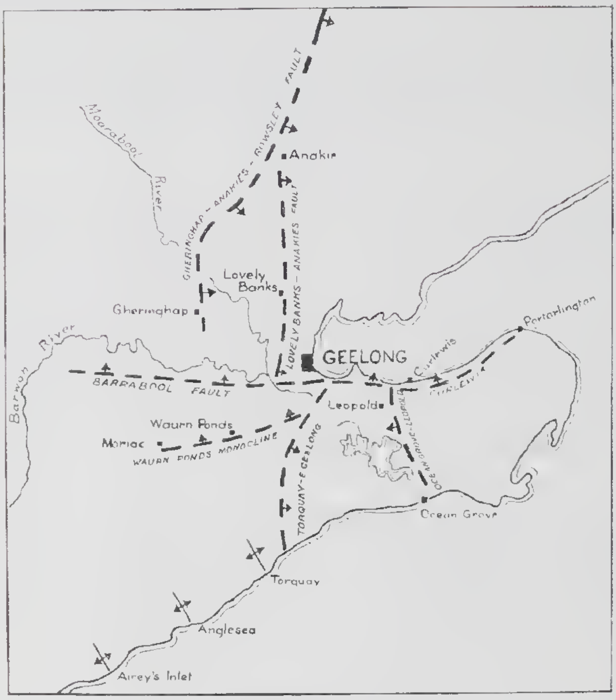

Fig. 1.- Faults in the Geelong District.

2. Anakie-Lovely Banks fault.

A normal fault commences at the central hill of the Anakies and extends nearly 20 miles south to near Fyansford Hill, running parallel to the Rowsley fault and about 5 miles to the east of it. The maximum throw of about 150 feet is in the middle section near Lovely Banks. Here again Pleistocene Newer Basalt has been displaced, the downthrow being to the east. The fault is therefore late Pleistocene or later.

3. Barrabool Hills-Curlewis fault.

The northern face of the Barrabool Hills is a demonstrable fault scarp, with a throw of 300 feet to the north near Ceres. The Barwon River flows along the fault line between Pollocksford and Fyansford. Originally noticed by Hall (1911), the fault was named the Barrabool Fault by Fenner (1918), and has been referred to as the Barwon Fault (Coulson 1930) but the prior name is here retained.

The western end of the fault begins near Pollocksford, and although the eastern end appears to be in Queen's Park, Fyansford, this is not the case, as the fault penetrates Newtown Hill and extends east to form the southern shore of Corio Bay, curving to the north-east near Curlewis and probably ending at Portarlington.

It is difficult to assign any age, other than post-Miocene, to this fault, as the only rock which can be traced on both sides of the fault plane is Miocene limestone near Gugger's Hill, Ceres (Coulson 1930). However, if we consider the youngest rock in the low cliffs on the southern shore of Corio Bay to have been fractured by the fault, this is the Pleistocene limestone (Pritchard 1895) of Limeburner's Point, and in that case the fault occurred in late Pleistocene or sub-Recent times.

A note may be inserted here regarding the existence of a fault between Batesford and Fyansford, postulated by some authors. Between these two plaees the Newer Basalt occupies two distinct levels; on the eastern side of the Moorabool River it is at 200–250 foot altitude, while on the west it is at 100 foot altitude. To account for the lower level basalt, hinge faulting has been suggested (Fenner 1918), the let-down block lying between two faults. The East-West Barrabool fault and a hypothetical North-South fault running from Batesford to Fyansford. The latter " fault " does not exist, as was proved in 1926 by the bores put down by Australian Cement Ltd. to test the thickness of limestone in their new quarry at Batesford. It was discovered that the limestone throughout the area tested was undisturbed, whereas if a fault had traversed it there would have been a displacement of 150 feet. The difference of level in the basalt flows is due to the fact that they are separate flows (Coulson 1937), the lower one filling a stream-eroded valley.

4. *Moolap-Leopold trough fault.*

Stretching from north to south between Corio Bay and the Connewarre Lakes is a flat strip of country, scarcely 10 feet above sea level, bounded on the east by the Leopold-Kensington Hill, and on the west by the East Geelong Hill. It may be called the Moolap sunkland. Bores in the sunkland (Coulson 1935) reveal much the same sequence as in the bordering hills, though of course at nearly 100 feet lower level. The structure appears to be a genuine trough fault, the bordering hills representing the former fault scarps. The western fault extended from Limeburner's Point south to Torquay, and the eastern from Curlewis to Ocean Grove. The Newer Basalt has been displaced, so the fault would probably be late Pleistocene.

5. *Corio Bay-Port Phillip Bay-Bass Strait faults.*

The southern shore of Corio Bay has been proved to be the eastern extension of the Barrabool fault. The bay has a depth of about 30 feet in most parts, but becomes very shallow on the northern shore near Corio and Avalon. It is probable that there is no actual fault on the north side, and that the bay was formed by tilting towards the south. In this case, the short section of cliff at the extreme western end of the bay, between Western Beach and North Shore, must be a minor fault scarp, running north-south.

Corio Bay is, of course, only the western extension of Port Phillip Bay, the origin of which is attributed to faulting, with the maximum throw on the east side along Selwyn's fault. This paper is concerned only with that portion of the faulting which delimited the Bellarine Peninsula. Presumably there was a small fault along the coast from near Portarlington past St. Leonard's to Queenscliff and Point Lonsdale.

Little is known of the foundering of Bass Strait, but it is reasonable to suppose that the faults along the Victorian coast were parallel to the present shore line, and probably not far from it.

6. *Otway Ranges faults*

Recent field work by the author in the Otway Ranges has shown that over about 80 per cent. of the area, the Jurassic rocks dip to the south-east at about 15°. There are about half-a-dozen small areas, however, where this direction of dip does not hold. These are shown on the sketch map (Fig. 2). Unfortunately the field work is not yet advanced to the stage of plotting the numerous faults which have produced these tilted blocks in which the dip differs from the normal. There is no evidence of age available at present

Fig. 2.—Areas of abnormal dip in the Otway Ranges.

FOLDS.

1. *Waurn Ponds Monocline.*

A downwarp of about 60 feet to the north occurs in the Miocene limestone at Waurn Ponds, and runs E.N.E. for several miles until obscured by younger sediments, but probably extends across the hiatus of the Moolap sunkland to Curlewis, where there is a disturbed area. A flow of Newer Basalt from Mount Duneed crosses the monocline just west of the Waurn Ponds quarries (Quarter Sheet 28 N.E.) without notable diplacement, so possibly the monocline is a pre-basaltic feature.

2. *Curlewis contorted beds.*

The Tertiary beds at Curlewis beach and Clifton Springs have suffered from intense folding and minor faulting (Coulson 1933). The locality appears to lie at the intersection of several lines of weakness, viz., the Barrabool Hills-Curlewis fault, the Leopold-Kensington fault, and the extension of the Waurn Ponds monocline

3. *Torquay, Anglesea, and Airey's Inlet folds.*

Open folds occur in the Tertiary beds exposed in the coastal cliffs between Lorne and Ocean Grove, with anticlinal structures at Airey's Inlet, Anglesea and Torquay, and synclines between. A gentle synclinorium has thus developed, and its origin must be discussed. Hills (1935) considers that the folding is due to the differential uplift of the Otway Ranges (and consequent lateral pressure). In this case, the folding should be most intense near the Otways, but actually it is greatest at Torquay. The folding is to be attributed to sagging in the geosyncline of the Tertiary sea, for we know that the Tertiary beds form a tapered series, thin in the north and west, and thickest in the south-east, where differential subsidence must have occurred. This folding would thus be contemporaneous with the deposition.

4. *Folding in the Otway Ranges.*

In the valley of the Wild Dog Creek about 6 miles from Apollo Bay there is exposed in a road cutting a small monocline in the Jurassic mudstones. It was originally noticed by V. Stirling (1901). At the extremity of Cape Otway, the Jurassic sandstones of the shore platform form a pitching anticline, the western leg dips north-west at 9 degrees, and the eastern dips north-east at 10 degrees. In the cliff just below the lighthouse there is a large fissure, which is apparently not connected with the anticline.

Both these structures appear to be local, and are probably due to sagging of competent beds. Usually in the Jurassics, earth-movements have resulted in faulting, but there are some small folds such as those described.

Upper Cainozoic Vulcanicity.

Starting in Upper Pliocene times and reaching a maximum in the Pleistocene, numerous volcanoes exuded the huge quantities of lava necessary to form the basalt plains of the Western District and Werribee fields. The petrological aspects have already been treated (Coulson 1937). Here we must consider the relation between the volcanic activity and the faulting, and the effect of the lava flows upon the drainage system.

It is the common phenomenon to find that the basalt boulders apparently clothe the face of the fault scarp, and Fenner (1918) has exhaustively discussed the three possible explanations, viz.:—

(*a*) the basalt flowed over a pre-existing fault scarp and solidified on the slope;

(*b*) the fault developed as the basalt was flowing or still plastic, the two being contemporaneous;

(*c*) the fault was later than the basalt, and displaced it, but the shattered basalt remained as partly buried blocks on the slope.

In the Geelong district the third of these processes seems to have been operative, and most of the faults are therefore late Pleistocene or Holocene.

After the major uplift which brought the Tertiaries above sea level, and before the eruptivity, a level plain stretched between the highlands of Ordovician rock in the north, and the Otway Ranges in the south. The original streams had begun to traverse this plain, the upper beds of which consisted of easily eroded Pliocene sands. Then came the floods of lava, filling the valleys and later forming a smooth field of lava with a gentle slope to the south. Bores through this basalt sheet have revealed the courses of the deep leads (Hunter 1909), and also show that the lava is much thicker along its northern margin (200 feet) than it is on the southern (about 30 feet). The general trend of the drainage was unaltered, although numerous small lava barriers interrupted the streams temporarily, especially in the case of the ancestral Moorabool.

Development of the Drainage System.

It is probable that the present drainage system is engrafted on that of pre-Tertiary times, at least in a general sense. The south-flowing streams from the northern highlands of the Divide, and the north-flowing streams from the Otways, originally discharged into the central arm of the Tertiary sea, which extended from Birregurra to Shelford and from Maude to Geelong. After the major uplift, these streams united on the Tertiary plains, and owing to the prevailing south-easterly dip of about 5 degrees that the Tertiaries have, the combined stream became a consequent river, the ancestral Barwon. Discharge was increased owing to the rejuvenation of the headwaters in the Divide and the Otways, and permanent valleys established.

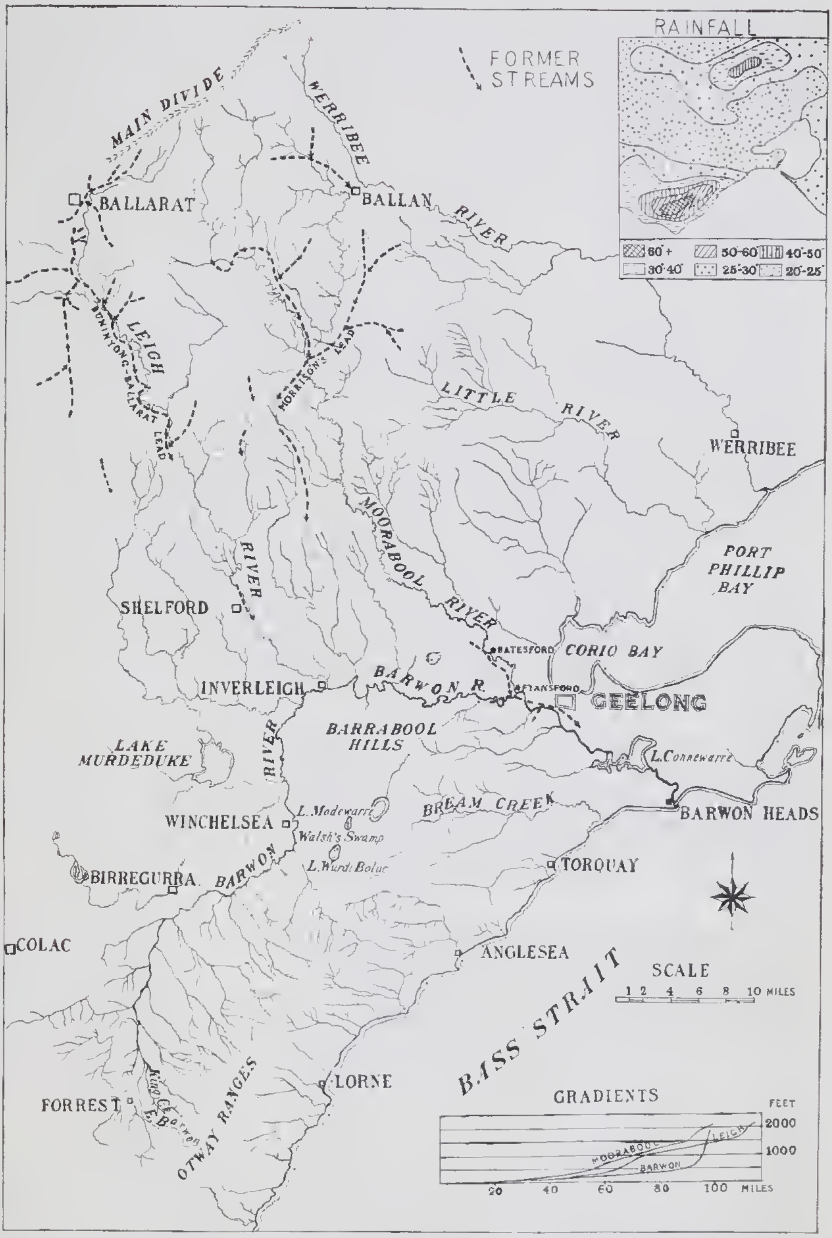

FIG. 3.—The Barwon-Leigh-Moorabool Drainage System.

The lava extrusions of the Newer Volcanic era did not materially affect the trend of these valleys, but led to entrenching and further rejuvenation. Relics of the basalt-filled valleys, shown in Fig. 3, occur at Durham Lead (Etheridge and Murray 1874), Shelford Lower Flow (Dennant and Mulder 1898), Morrison's Lead (Hunter 1909), She Oak Falls (Quarter Sheet 19, S.W. Note 2), and a hitherto undescribed flow extending from Batesford (Lower Flow) to Queen's Park, Fyansford, then through Newtown, Chilwell, South Geelong, Breakwater, and St. Alban's where it disappears beneath Recent sediments.

This flow fills a valley which was cut by the Moorabool River through the granite of the Dog Rocks, and extended south to Queen's Park where it junctioned with the Barwon at Buckley's Gorge. The former bank of this flow can be seen in Tertiary limestone exposed in a basalt quarry near Fyansford Bridge. The basalt-filled valley skirts the south side of Queen's Park at a high level, has been breached by the Barwon at Queen's Park Bridge, and crosses Newtown Hill to descend to Marnock Vale, where it received a small tributary from the direction of Highton, now seen as a residual on the east side of Prince's Bridge. This temporary barrier caused the formation of Harrison's Flats (terraced) on the west side of Prince's Bridge, and the accumulation of gravel and slate pebbles at Marnock Vale. There is no doubt that this stream was at one time the Barwon River, and it is important to remember its course when considering the former outlet of the river.

The present Barwon River rises from springs in the Otway Ranges near Mount Sabine, with tributaries starting at intervals along the north side of the main ridge towards Benwerrin. River capture has occurred where the former upper tract of the East Barwon is now occupied by the "big" King Creek (Gregory 1912).

Rich alluvial fans mark the debouchment of the Otway creeks on to the Tertiary plains. A bore at Barwon Downs showed 176 feet of sand and silt. Union of most of the tributaries is effected before Birregurra is reached; the river then proceeds to Winchelsea, where a right-angled turn takes it north to Inverleigh. Here it receives the Leigh River and reverts to its easterly course towards Geelong.

The right-angled turn of the Barwon at Winchelsea, was considered by Hall (1910) to be due to interference by basalt flows, from west of Winchelsea, with the original course of the Barwon, which, he said, coincided with that of the present Thompson's Creek (Bream Creek). This is a very tempting inference from the fact that a wide valley occurs between the Barrabool Hills and the Otway Ranges, partly filled with basalt, and occupied by the insignificant Bream Creek. Closer examination reveals:—

(1) that the basalt did not come from "west of Winchelsea" but from a number of local vents, viz., a 550 ft. hill north of Wurdi Boluc, a 450 ft. hill near Winchelsea, Mt. Moriac, Mt. Duneed, and a hill near Pettavel, all rather local flows between which the river could easily have found its way;

(2) the Tertiaries between the valleys of the Barwon River and Bream Creek are the same height as the others of that locality, i.e., about 350 feet, and show no sign of a former deep valley having been filled with basalt;

(3) certain lakes in the valley, such as Lake Wurdi Boluc, Lake Modewarre, Walsh's Swamp, &c., which appeared to be remnants of a former large stream, have their beds partly in Tertiaries as well as basalt, and these beds are higher than the river level.

The supposed alteration of course is therefore not admitted, and the view is held that the Barwon always flowed to the west and north of the Barrabool Hills as it does at present, though possibly somewhat to the west of its present course.

Lake Murdeduke, west of the Barwon River between Winchelsea and Inverleigh, does not overflow to the Barwon, though some maps suggest that there is an outlet stream. A basalt ridge about 20 feet high separates the lake from the head of an intermittent creek which drains to the Barwon.

The Leigh and Moorabool Rivers commence as springs on the southern slopes of the Main Divide near Ballarat and Korweinguboora respectively and flow south, traversing Ordovician and Newer Basaltic rocks. Some waterfalls occur where the basalt flows have suffered headward erosion, e.g., at the Lal Lal Falls and the Moorabool Falls, or where lava barriers are encountered, as at the She Oak Falls.

Near Ballan the courses of the Eastern Moorabool and Werribee rivers approach very close, and Fenner (1918) considers that in pre-Newer Basaltic times both belonged to the Werribee system, the Eastern Moorabool later being captured by a stream which approached from the south.

A palpable error by Gregory (1912, p. 123) has left the widespread belief that the former mouth of the Barwon was in Corio Bay. The basalt which extends from Fyansford to Corio Bay was regarded by him as filling a former valley, but excellent cliff sections and road cuttings reveal that the basalt is part of a thin uniform sheet. From what has previously been said about the basalt-filled valley between Queen's Park (Fyansford) and Chilwell, it will be seen that the former Barwon always kept to the south side of the Newtown Hill, and entered the sea somewhere near its present mouth.

Conclusions.

1. The Otway Ranges constituted an island in the Tertiary sea.

2. Earth-movements of late Pleistocene age were responsible for most of the present topography.

3. The drainage system began in pre-Tertiary times, and engrafting took place after the post-Tertiary uplift.

4. The flows of Newer Basalt did not seriously interfere with the courses of the rivers. The Barwon did not flow along the valley of Bream Creek, nor was its mouth in Corio Bay.

Acknowledgments.

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